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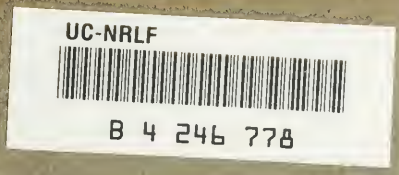
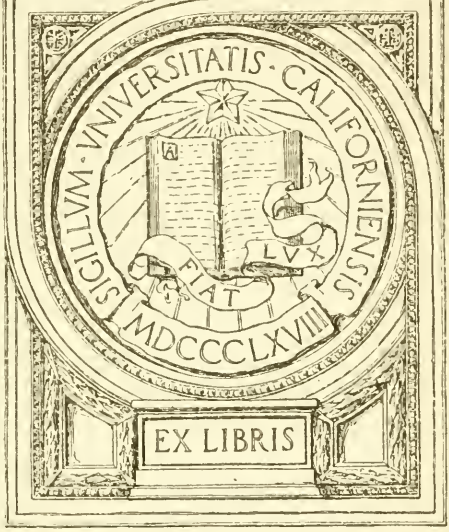


IN MEMORIAM

Prof. J. Henry Senger



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THE

MANNHEIM

SLIDE RULE.

COMPLETE MANUAL.

WITH TABLE OF SETTINGS, EQUIVALENTS AND GAUGE POINTS.

BY WM. COX.

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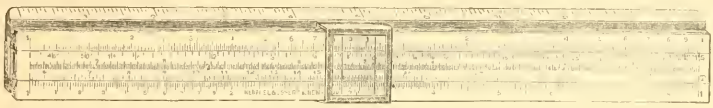

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THE SLIDE RULE.

BY WM. COX.

1.—INTRODUCTION.

As the usefulness of the Slide Rule for facilitating the working out of complicated calculations is not confined to the Engineer alone, but may be equally taken advantage of by the Merchant, Importer, Exporter, Spinner, Manufacturer, etc., we purpose in these introductory remarks to explain as briefly and simply as possible the principles upon whose basis this instrument is constructed. To those who are in the habit of using tables of logarithms, these principles will be self evident. We therefore request them to excuse the introduction of this, to them, irrelevant matter.

There is a very general impression that the acquirement of a facile use of the Slide Rule is both tedious and difficult. This, however, is not the case. It may be easily learnt in spare moments, advantage being taken of these to attain to proficiency by frequent practice.

The construction of the Slide Rule is based upon logarithms, but the principles which require mastering are few and simple, and a little attention to the following observations will enable any one to understand them. Each step of the ladder once firmly gained will then become, not only an incentive, but an opening up of the way to mount higher, by showing the logical consequences of the knowledge already acquired.

Two general principles must at the outset be clearly understood, viz :

1st. A *unit* may be represented by a SPACE of any length measured off from a given point : and a *number* composed of two or more units may be represented by a DISTANCE composed of the same number of spaces. These distances may be increased by adding or joining on to them other spaces or distances, or decreased by taking from them some of the spaces or distances of which they are composed.

2d. Logarithms are a series of numbers in Arithmetical Progression (as 0, 1, 2, 3, 4, etc.), corresponding to another series of numbers in Geometrical Progression (as 1, 2, 4, 8, 16, etc.)

We will take two such series and place them together, thus : —

0	1	2	3	4	5	6	7	8	9	10
1	2	4	8	16	32	64	128	256	512	1024

Here the first line is a series of numbers in A. P. and they are the logarithms of the corresponding numbers in the second line, which is a series of numbers in G. P.

A little examination of the peculiar properties of these two series will enable us to

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understand how these properties have been taken advantage of and applied to the Slide Rule.

1st. If we add together any two numbers of the first line as 3 and 5, their *sum* 8 corresponds with 256 of the second line. Now 256 will be found to be the *product* of the two factors 8 and 32, which on the second line correspond with 3 and 5 on the first line.

2d. If we subtract one figure of the first line from any other figure of the same line, as 9 minus 6, their *difference* 3 corresponds with 8 of the second line, and 8 will be found to be the *quotient* of $512 \div 64$, which on the second line correspond with 9 and 6 on the first line.

3d. If we multiply any figure of the first line by 2, as 3×2, the *product* 6 corresponds with 64 of the second line, which is the *square* of 8, which on the second line corresponds with 3 on the first line.

4th. If we divide any figure of the first line by 2, as $8 \div 2$, the *quotient* 4 corresponds with 16 of the second line, and this 16 is the *square root* of 256, which on the second line corresponds with 8 of the first line.

5th. Likewise, if we multiply or divide by 3, 4, etc., we obtain the 3d, 4th, etc., power or root.

These are the peculiar properties of logarithms, which are of such immense advantage in the working out of abstruse calculations, and they have been applied to the Slide Rule by means of our first general principle.

A series of *equal* spaces are taken to represent the numbers of the series in arithmetic progression, and to these are affixed the corresponding numbers of the geometric series.

If we thus take any given length, say ten inches, and divide it into 1000 equal parts, and if against the starting point or zero we place the figure 1, then at the end of 301 parts we place the figure 2; at the end of 602 such parts we place the figure 4; and at the end of 903 parts we place the figure 8, we obtain a logarithmic scale, which, to complete it, merely requires assigning to it the exact position of the other and intermediate figures up to 10. Such a scale is found on the Slide Rule; the Slide, which is marked like the Rule, being for the purpose of adding or joining a given number of spaces on to any other given number of spaces taken on the Rule, just as if we marked off three inches on a sheet of paper, and taking two inches in the opening of a pair of compasses or on a slip of paper, joined these on to the former three, thus indicating on the sheet of paper the position of 5, or the *sum* of 3 and 2; but with this difference, that on the Slide Rule the adding of 2 spaces to 3 gives the *product* 6 and not the sum 5. In the same way, the Slide serves to take any number of spaces from any other given number on the Rule, the result of which, equivalent to subtraction in ordinary arithmetic, becomes division when a logarithmic scale is used.

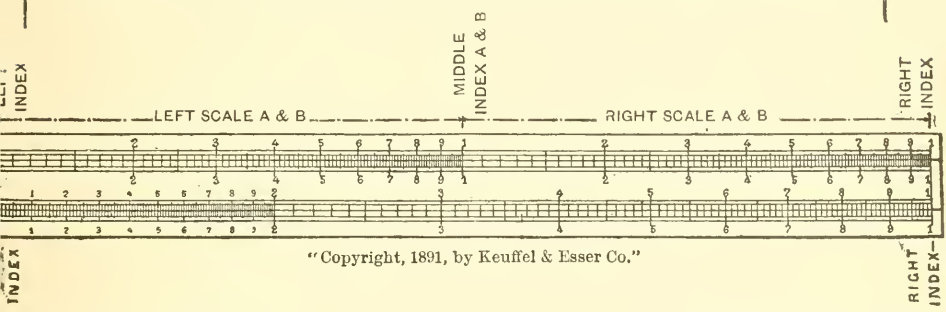
The various operations therefore of Multiplication, Division, etc., are performed exactly as described in the case of two series of numbers in arithmetical and geometrical progression.

2.—DESCRIPTION OF THE MANNHEIM SLIDE RULE.

The Slide Rule, as recently perfected by Mannheim, an officer of Artillery at Metz, is generally made of well-seasoned box-wood, and is about 10 inches long, $1\frac{1}{2}$ inches

broad, and $\frac{1}{4}$ to $\frac{3}{8}$ inches thick. In a later form introduced by us, and embodying the same improvement, it is made of mahogany and faced with *celluloid*, on which are engraved the graduations, the strong contrast between the white ground of the celluloid and the black lines rendering the "reading" easier than in the case of the less distinct graduations on wood. Along the centre a slip of the same material *slides* easily from left to right and right to left, in a groove to which it is accurately fitted, its face being perfectly level with the Rule. This is the Slide.

Reference to the accompanying figure will make the following explanations clear.



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On the Rule will be seen, along its whole length, and close to the upper edge of the groove, a series of graduations, with an identically similar series along the upper edge of the Slide. These form the upper scales, called for easy reference A and B.

Another series of graduations will also be seen on the Rule along the lower edge of the groove, with a corresponding series on the Slide. These are called C and D, and are the lower scales. The starting or initial points of each scale on the left hand, marked 1, are the left indices, and the terminating points on the right, marked also 1, are called the right indices. It will be seen that the scales C and D are numbered 1, 2, 3, etc., from the left to . . . 9, 1 on the right. (The reason why this latter is not marked 10 will be explained shortly.) As would be gathered from our introductory remarks, it will be found that the space from 1 to 2 is the same length as that from 2 to 4, and also from 4 to 8. It is therefore a logarithmic scale, and joining on the distance 1 to 2 to itself by means of the slide, gives the product of 2×2, or 4. So also joining on the distance 1 to 2 to the distance 1 to 4, gives the product of 4×2, or 8.

That portion of the scales on C and D between 1 and 2 will be seen to be again divided into ten parts, also marked 1, 2, 3, etc., and each of these parts is again divided into ten other small parts. These subdivisions would be carried throughout if the spaces admitted of it, but on account of their decreasing size, they are afterwards divided into ten parts and subdivided into halves or fifths, which must be considered as decimal divisions and not fractional ones.

It must now be clearly understood that the figures as marked are arbitrary, and that the initial 1 or left index may have *any value* which is a decimal part or a multiple of 1, assigned to it, such as 10, 100, .1, .01, etc., but this same ratio must be observed throughout the whole scale, which then becomes 20, 30; 200, 300; .2, .3; .02, 03, etc. All the subdivisions are consequently decimal ones, and have their real value assigned to them by the fixing of the position of the decimal point, which depends upon the primary value given to the initial 1. If, for example, we give the left index the value of 100, the other figures will be 200, 300 . . .

900, 1000. The divisions between the left index and 2 will be 110, 120 . . . 190, 200, and the subdivisions between the initial 1 and the following small 1 will be 101, 102 . . . 109, 110. The subdivisions between 2 and 3 will be 202. 204 . 208, 210, and the divisions will be 200, 210, 220 . . . 290, 300. From 4 onwards there are ten divisions between each two figures, which are again subdivided into halves. Assuming the left index to be still 100, these become 400, 405, 410, 415 . . . . 485, 490, 495, 500, and so on to the right index. It will therefore be seen that from 1 to 2 there are graduations which indicate the exact position of numbers composed of three figures; from 2 to 4, for numbers of two figures and fifths; and from 4 to the end of the scales, for numbers of two figures and halves. As we have stated, the value of the initial 1 may vary, so any of these numbers, such as 485, may have the value of 48.5; 4.85; .485; 48500, etc. This real value is entirely dependent upon the problem to be solved. If a number of more than three figures be needed, the position of the others must be "estimated" by the eye; and a little practice will soon render the operator proficient, so that he will be able without difficulty to read off all numbers of three and four figures.

If lines A and B of our illustration be now examined, it will be at once noticed that there are on the Rule, as also on the Slide, two distinct but similar scales, each marked exactly alike from the left index 1, 2, 3 . . . 9, 1, to the middle index, and then commencing again 1, 2, 3 . . . 9, 1, ending at the right index. If we give to the left index on the upper and lower scales the value of 1, we shall have on A and B, scales from 1 to 10, and from 10 to 100, each space of which is exactly half of the corresponding space on C and D. It will further be seen that 2 on the lower scales coincides with its square 4 on the upper scales, 3 with its square 9, and 10 on the lower scales with its square 100 on the upper scales. The scales A and B, being (numerically considered) twice as long as the scales C and D, are by reason of their graduations, and according to the third and fourth properties of logarithms, as explained in the introduction, scales of *squares* of all their coinciding numbers on C and D. In like manner scales C and D form *square roots* of all their coinciding numbers on A and B.

Each instrument is provided with a brass or glass Runner, which enables coinciding points to be found on any of the scales, and also permits of extensive calculations being worked out without the necessity of "reading off" the intermediate results, thus securing a greater degree of accuracy in the final one.

Such is the complete Mannheim Slide Rule. Its successful use lies largely in the ability to read the graduations rapidly and correctly. This can only be acquired by actual practice. It must ever be borne in mind that whatever value is assigned to the left index, all the graduations are *decimal* ones whose real value depends upon that of the index; also that a fixed relationship exists between the upper and the lower scales, and that whatever be the initial value of C and D, the initial value of A and B *must* be its *square*.

3.—HOW TO USE THE SLIDE RULE.

Multiplication, Division, Proportion.

All calculations in multiplication, division and proportion are worked out on scales C and D, as by reason of the greater space allotted to each of the divisions, the results obtained are more accurate. We shall commence with proportion, as into it are resolved in reality, and with the Slide Rule, *in actual practice*, all sums of multiplication and division.

A leading principle of the Slide Rule is that, place the Slide as we will, *all* the numbers on the Slide bear the *same proportion* to their coinciding numbers on the Rule. Let us take the proportion or ratio of 2 to 4. We draw out the Slide towards the right until 2 on C is exactly over or coincides with 4 on D. It will then be seen that this ratio of 2 to 4 exists between every pair of coinciding numbers, as 1 : 2, 3 : 6, 42 : 84, 115 : 230, etc. So with any other ratio. It is evident, therefore, that if we set the two first terms of a proportion against each other on the Slide and Rule, we shall find the third term on the Slide coinciding with the fourth term on the Rule. We have, therefore, the following general statement:

$$\left.\begin{matrix}\text{Any number}\\ \text{on C}\end{matrix}\right\} : \left\{\begin{matrix}\text{The number}\\ \text{under it on D}\end{matrix}\right. :: \left.\begin{matrix}\text{Any other}\\ \text{number on C}\end{matrix}\right\} : \left\{\begin{matrix}\text{The number}\\ \text{under it on D}\end{matrix}\right.$$

We will now give the rule, and that in a diagrammatical form, which appeals to the eye, and simplifies the putting of it in practice, thus:

C	Set first term	Under third term
D	Over second term	Find fourth term;

the full meaning of which is, set the number corresponding to the first term on Slide C over the number corresponding to the second term on Rule D, and under the number corresponding to the third term on Slide C will be found the number corresponding to the fourth term on Rule D.

The reader is requested to take note of this formula or manner of stating a rule, as the same plan will be adopted throughout. It shows graphically the method of procedure, and is much simpler than a long statement in words.

Example: $12 : 21 :: 30 : X$, or $\frac{21 \times 30}{12} = 52.5$.

C	Set 12	Under 30
D	On 21	Find 52.5—Answer.

We shall not give here the rules for the position of the decimal point, or for ascertaining of how many figures the integral portion of the answer is composed, as they will be given in full further on. In most cases in actual practice it is self-evident, or easily determined by a glance at the figures of the problem.

This principle of similar proportions or ratios is one of the most important advantages of the Side Rule, as it enables a vast number of calculations to be made in the simplest manner possible. Thus, to find the circumference of a circle from its diameter,

C	Set 226	Under ANY diameter
D	On 710	Find corresponding circumference.

The figures 226 and 710 express the ratio which always exists between the diameter of a circle and its circumference, and is equal to 1 : 3.14159, being correct to six places of decimals. Such ratios are termed Equivalents or Gauge Points, and being given in this form are much easier to set on the Slide Rule than the ordinary form of reciprocals. These equivalents may be worked out for any class of trade, for the

Engineer, the Importer, the Exporter, etc. Thus a ratio or gauge point may be found to express in dollars per yard the price of French silks at so many francs per metre.

Example: What would be the price, in dollars per yard, of goods bought at 4 francs per metre, exchange being taken at $3.80 for 20 francs?

C	Set 800	Under 4
D	On 139	Find 695=69½ cents per yard.

A table of values in dollars per yard could thus be made out with the greatest facility and exactitude.

We have said that MULTIPLICATION and DIVISION resolve themselves into proportion, for what else is the proportion 1 : 4 : : 3 : 12 but a simple sum in multiplication, 4 and 3 being the two factors, and 12 being their product. With the Slide Rule this becomes

C	Set 1	Under 3
D	On 4	Find 12—the product.

The rule for MULTIPLICATION is therefore

C	Set 1	Under the other factor
D	On one factor	Find their product.

So of Division, which is merely the reverse of the above, and the proportion becomes 3 : 12 : : 1 : 4, and on the Slide Rule

C	Set 3	Under 1
D	On 12	Find 4—the quotient.

The rule for DIVISION is therefore

C	Set divisor	Under 1
D	On dividend	Find the quotient.

In these two examples the expressions "Set 1" and "Under 1" refer to either the left or the right index, according as the circumstances of the case require.

It will be found in some cases that the result of an operation lies beyond the rule either to the right or the left. For instance, the full working out of the example giving the price of French silks would be

C	Set 800	Bring Runner to right index	Draw slide to the right until left index is under Runner	Under 4
D	On 139			Find 695.

With the ordinary Slide Rule, the result of the first setting, which is the quotient of 139 ÷ 800, would have to be "read off," and the left index of the Slide set to it, so that the multiplication of this result by 4 might be effected. The use of the Runner does away with this, and consequently diminishes the chances of error which might be

caused by an incorrect reading or re-setting of the Slide. The Runner is also of immense advantage when several factors have to be multiplied together, the final result being alone noted.

Example: $12 \times 4 \times 5 \times 3 = 720$ is worked thus:

C	Set 1	Runner to 4	1 to Runner	Runner to 5	1 to Runner	Under 3
D	On 12					Find 720—Answer.

In the same way several divisions can be easily performed, and also a combination of multiplications and divisions, as in the case of a train of wheels, as

$$\frac{71 \times 21.4 \times 35 \times 17}{8.5 \times 42 \times 5.8 \times 20} = 21.8,$$ which is worked thus:

C	Set 85	Runner to 214	42 to R	R to 35	58 to R	R to 1	20 to R	Under 17
D	On 71							21.8—Answer.

A little practice will enable similar problems to be worked out with ease. No notice has so far been taken of the real position of the decimal points the finding of which has been left to inspection, which in many problems is all that is necessary. We now give the rules in full with examples and explanations.

4.—THE POSITION OF THE DECIMAL POINT.

The following are the rules for ascertaining the number of digits or figures of which the integral portion of any result is composed, or, in other words, the position of the decimal point. The number of figures in the integral part of a number is called its *characteristic*, thus:

2	is	the	characteristic	of 24.135.
1	"	"	"	2.730.
0	"	"	"	0.583.
—1	"	"	"	0.079.

Multiplication.—If the product is obtained with the Slide projecting to the *left*, its characteristic is the *sum* of the characteristics of the two factors; but if the Slide projects to the *right*, the characteristic of the product is the sum of the characteristics of the two factors *less* 1.

Example: $45 \times 2.5 = 112.5$.

The sum of the characteristics of the two factors is 3, and the Slide projects to the left, therefore the integral portion of the product is composed of three figures.

Example: $3.3 \times 18 = 59.4$.

The sum of the characteristics of the two factors is 3, but to obtain the result, the Slide projects to the right. The product contains, therefore, $3 - 1$, or two figures only in the integer.

Division.—If the quotient is obtained with the Slide projecting to the *left*, its characteristic is the characteristic of the dividend, minus the characteristic of the divisor; but if the Slide projects to the *right*, this difference must be *increased* by 1.

Example: $33 \div 7.5 = 4.4$.

The characteristic of the dividend, less the characteristic of the divisor, is 1, and as the Slide projects to the left, the integral part of the quotient contains one figure.

Example: $65.1 \div 21 = 3.1$.

The characteristic of the dividend, less the characteristic of the divisor, is 0, but as the Slide projects to the right, the quotient contains $0 + 1$, or one digit in its integral portion.

These four rules may be put into the following form, so that the eye may "catch" them at once.

	When the SLIDE Projects to the	
	LEFT	RIGHT
	the CHARACTERISTIC of the RESULT is the	
MULTIPLICATION	SUM of the Characteristics of the 2 factors.	SUM—1 of the Characteristics of the 2 factors.
DIVISION	Characteristic of DIVIDEND, less char'c of DIVISOR.	Characteristic +1 of DIVIDEND, less Char'c of DIVISOR.

PROPORTION.—Special rules might be given, but we believe the simplest plan is to adopt the preceding ones. The first operation being division, the characteristic of the quotient is easily obtained; this quotient being then one of the factors in the succeeding multiplication, the final characteristic is found by the rule already given.

Example: 12 : 21 : : 30 : 52.5.

1st operation, $21 \div 12$. Slide on right gives $(2 + 1) - 2 =$ characteristic 1.

2d operation, quotient $\times 30$. Slide on right gives $1 + (2 - 1) =$ characteristic 2, that is, there are two figures in the integral part of the answer. In ordinary practice, and especially in the case of combinations of multiplications and divisions, the characteristics would be set down in the order in which they occur. Thus in the example of combinations, we have $1 + 2 - 2 + 2 - 1 - 2 + 1 + 1 = 7 - 5 = 2$ figures in the integral portion of the result, which becomes 21.8. A little study and practice will make these rules self-evident, and their application very easy.

5.—THE INVERTED SLIDE.

It frequently happens that in proportion *more* requires *less*, or *less* requires *more*. This is Inverse Proportion, and is most simply worked out by *inverting* the Slide, so that C shall lie along A, and B along D. The lines C and D then form throughout a series of inverse ratios, the "reading off" of which is effected by means of the Runner.

Example: If 6 men can build a wall in 4 days, how long will it take 12 men to build it?

This becomes $6 : 4 : : 12 : 2$, or $\frac{6 \times 4}{12} = 2$, and on the Slide Rule

C Inverted	Set 6	Under 12
D	To 4	Find 2—Answer.

As proportion is composed of the two operations of multiplication and division, it naturally follows that these can be also worked out with the Slide inverted. The following are the formulæ:

Multiplication.	C Inverted	Set one factor	Under 1
	D	To other factor	Find product.

Division.	C Inverted	Set 1	Under Divisor
	D	To Dividend	Find Quotient.

It will be noticed that the *product* of all the coinciding numbers on C and D is equal to the number found on D, under either index on C, thus:

C. Inv'd	Set 1	Find 9	8	6	4.8	4	3	2.4	2
D	To 144	16	18	24	30	36	48	60	72

In this way a series of factors is obtained whose product is always the same. A great many other calculations are worked out with advantage with the Slide inverted, illustrations of which are given further on. The rules for the position of the decimal point are just the reverse of those already given.

It may be interesting to some readers if we add a few words respecting the Inverted Slide. If the Slide is thus placed in the Rule with the right and left indices corresponding, it will be found that the product of every number on the Slide and its coinciding number on the Rule is always 10 or unity: whence it follows that the numbers on the Slide are the *reciprocals* of their coinciding numbers on the Rule, and vice-versa.

The rule for multiplication, with the Slide in its ordinary position, requiring one factor to be taken on the Slide, it follows that that factor, if the Slide be inverted, is the reciprocal of some other number, and multiplying by it in the ordinary way becomes consequently equivalent to dividing by that other number. Hence, the rules for multiplication, division and the decimal point are exactly reversed when the Slide is inverted.

6.—THE UPPER SCALES, AND SQUARES AND SQUARE ROOTS.

It has already been shown that all the numbers on scales A and B are the squares of their coinciding numbers on C and D, and also that the numbers on scales C and D are the square roots of their coinciding numbers on A and B. When a square or square root is sought, all that is necessary is to place the Runner to the given number

on A or D, and the coinciding number on D or A will be the square root or the square. But combinations, such as $a^2 \times b$, $a^2 \div b$, etc., can also be solved with the utmost facility, thus:

$a^2 \times b = x$

Example:
$8^2 \times 5$

A		Find x.	
B	Set 1	Over b	
C			
D	To a		

A		Find 320—Answer.
B	Set 1	Over 5
C		
D	To 8	

$a^2 \div b = x$

Example:
$12^2 \div 16$

A		Find x.	
B	Set b	Over 1	
C			
D	To a		

A		Find 9—Answer.
B	Set 16	Over 1
C		
D	To 12	

The formula $a^2 \times b = x$ is the one which gives the area of a circle when its diameter is known. The following setting, which is rather different, gives a complete table of diameters and areas.

A	Under 205	
B	Set 161	Find corresponding area.
C		
D		Over any diameter

Here 205 : 161 is equal to the ratio 1 : .7854, but is easier to set on the Slide Rule. A blue line on scale B gives the position of .785, and another that of 3.1416.

In the same way the CUBE of a number is easily found by means of the formula $a^2 \times a = a^3$.

Example:
$5^3 = 125$

A		Find a^3.	
B	Set 1	Over a	
C			
D	To a		

A		Find 125.
B	Set 1	Over 5
C		
D	To 5	

The finding of CUBE ROOTS is almost as simple. It may be done in two ways.

1st. Move the Slide from left to right, or from right to left, until the *same* figure is found, on B under the given number on A, and *also* on D under the left or right index of C. This figure is the cube root sought. This is clearly the inverse of the method for finding the cube of a number.

2d. Invert the Slide, set 1 on C under the given number on A, then look for the

number on B which coincides exactly with the *same* number on D. This number is also the cube root sought.

Example: Find the cube root of 216.

A	Under 216			A	Under 216		
B	Find 6		Or Inverted	C	Set 1		
C		and over 1		B		Under 6	
D		Find 6.		D		Find 6–Answer.	

7.—TRIGONOMETRICAL COMPUTATIONS.

On the *under* side of the Slide three scales will be found, the upper one, marked S, being a scale of natural sines, and the lower one, marked T, a scale of natural tangents. Between these is a scale of equal parts which gives the logarithms corresponding to the series of numbers on scale D.

In order to use these, place the Slide in the groove with the under side uppermost, and the left and right indices coinciding. On A will then be found the SINES of the angles given on S, those on the left scale A having the characteristic —1, and those on the right scale A the characteristic 0; thus we find

Sine 3° = 0.0523, on left scale A.
Sine 15° 10′ = 0.262, on right scale A.

We have on D the TANGENTS of the angles given on T, the characteristic being always 0, thus:

Tangent 25° = 0.466 on scale D.

The scale gives the tangents as far as 45 degrees only, those for larger angles must be found by the formula

$$\tan a = \frac{1}{\tan (90 - a.)}$$

Multiplication and division of sines and tangents are executed in the same manner as for ordinary calculations, thus:

Sine 3° 40′ × 45.

A	To 45	Find 2.875—Answer.
S	Set 1	Over 3° 40′

565 ÷ Tan. 14° 30′.

T	Set 14° 30′	Under 1
D	To 565	Find 2183—Answer.

Tan 75° 15′ × 175. Here tan 75° 15′ $= \frac{1}{\tan (90 - 75° 15′).} = \frac{1}{14° 45′}$, therefore

$$\tan 75^\circ 15' \times 175 = \frac{175}{\tan 14^\circ 45'}$$

T	Set 14° 45′	Under 1
D	To 175	Find 665—Answer.

The sines of angles may be found without reversing the Slide, by setting the given angle on scale S to the upper index on the under side of the Rule, and reading off the sine on B under the right index of A.

The Logarithms of numbers are found in a similar manner by setting the left index of C to the given number on D, and reading off the logarithm on the scale of equal parts against the lower index on the under side of the Rule.

Example: What is the logarithm of 5?

C	Set 1	Find on scale E. P. 699—Answer.
D	To 5	Against index on under side of Rule

With the scale of equal parts the cube and other roots or powers may be extracted, such as $X^{\frac{5}{2}}$, $X^{1.7}$, etc.

Example: Find $4^{\frac{5}{2}}$ or $\sqrt{4^5}$.

By above method $\log 4 = .602$, and $\log 4^{\frac{5}{2}} = .602 \times \frac{5}{2} = 1.505$. Now by placing 505 against the index on the under side of the Rule, we find 32 on scale D under the left index of C, which is therefore equal to $4^{\frac{5}{2}}$, the logarithmic index being 1.

The position of the decimal point in all these cases will be easily ascertained by those accustomed to this class of calculations. We do not give rules, as they would probably be found too tedious.

The new **K. & E. Patented Adjustable Slide Rule** (Patented June 5th, 1900) embodies an important improvement which prevents the slide becoming too tight or too loose from expansion or shrinkage of the rule or slide, even under extreme climatic variations.

Cross-section of Nos. 4030 to 4051.

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KEUFFEL & ESSER CO. NEW YORK.

We now give, by kind permission of "Engineering News," a number of settings for complicated formulæ, and also a very useful and complete table of Equivalents or Gauge Points, specially adapted to Slide Rule practice.

These will probably enable any one to work out similar Equivalents for any special class of calculations.

FORMULÆ. SETTINGS.

$$\frac{a^2 \times b}{c} = X.$$

A		Find X.
B	Set c	Over b
C		
D	To a	

$$\sqrt{\frac{a \times b}{c}} = X.$$

Inverted

A	To b	
C		Under c
B	Set a	
D		Find X.

$$a\sqrt{\frac{b}{c}} = X.$$

Inverted

A	Under b	
C	Set a	Under c
B		
D		Find X.

$$c\sqrt{\frac{a \times b}{d}} = X.$$

Inverted

A	Under b			
C			c to R	Under 1
B	Set a	R to d		
D				Find X.

or,

A	Under a			
B	Set d	R to b	1 to R	
C				Under c
D				Find X.

$\sqrt{\frac{a^3}{c}} = X.$ Inverted

A			
C			Under c
B	Set a		
D	To a		Find X.

$c\sqrt{b^3} = X.$

A				
B		R to b		
C	Set 1		1 to R	Under c
D	To b			Find X.

$\left(\sqrt{\frac{a \times b}{c}}\right)^2 = X.$ Inverted

A	Under a		Find X.
C	Set b		Over c
B			
D			

$\sqrt{\frac{a^2 \times b^2}{c}} = X.$ Inverted

A			
C	Set b		
B			Under c
D	To a		Find X.

To find the Geometric Mean, or Mean Proportional between two numbers, or $a : x :: x : b$

A		
B	Set less No. a	Below b
C		
D	To less No. a	Find X = G. M.

To reduce fractions to decimals.

C	Set numerator	Find equivalent decimal.
D	To denominator	Above 1

To reduce decimals to fractions.

C	Set decimal	Find equivalent numerators.
D	To 1	Find equivalent denominators.

EQUIVALENTS FOR SCALES C AND D.

GEOMETRICAL.

Set 226 = Diameters of circles.

To 710 = Circumferences of circles.

79 = Diameter of circle.

70 = Side of equal square.

99 = Diameter of circle.

70 = Side of inscribed square.

39 = Circumference of circle.

11 = Side of equal square.

40 = Circumference of circle.

9 = Side of inscribed square.

70 = Side of square.

99 = Diagonal of square.

205 = Area of square whose side = 1.

161 = Area of circle whose diameter = 1.

322 = Area of circle.

205 = Area of inscribed square.

ARITHMETICAL.

100 = Links.
66 = Feet.

12 = Links.
95 = Inches.

101 = Square links.
44 = Square feet.
6 = U. S. gallons.
5 = Imperial gallons.
1 = U. S. gallons.
231 = Cubic inches.
800 = U. S. gallons.
107 = Cubic feet.
22 = Imperial gallons.
6100 = Cubic inches.
430 = Imperial gallons.
69 = Cubic feet.

METRIC SYSTEM.

26 = Inches.
66 = Centimetres.

82 = Feet.
25 = Metres

82 = Yards.
75 = Metres.

87 = Miles.
140 = Kilometres.

4300 = Links.
865 = Metres.

43 = Chains.
865 = Metres.

31 = Square inches.
200 = Square centimetres.
140 = Square feet.
13 = Square metres.
61 = Square yards.
51 = Square metres.
42 = Acres.
17 = Hectares.
22 = Square miles.
57 = Square kilometres.
5 = Cubic inches.
82 = Cubic centimetres.
600 = Cubic feet.
17 = Cubic metres.

85 = Cubic yards.
65 = Cubic metres.
6 = Cubic feet.
170 = Litres.
14 = U. S. gallons.
53 = Litres.
46 = Imperial gallons.
209 = Litres.

108 = Grains.
7 = Grammes.
75 = Pounds.
34 = Kilogrammes.

6 = Ounces.
170 = Grammes.
63 = Hundredweights.
3200 = Kilogrammes.

63 = English Tons.
64 = Metric Tonnes.

PRESSURES.

640 = Pounds per square inch.
45 = Kilogs per square centimetre.
51 = Pounds per square foot.
249 = Kilogs per square metre.
59 = Pounds per square yard.
32 = Kilogs per square metre.
57 = Inches of mercury.
28 = Pounds per square inch.
82 = Inches of mercury.
5860 = Pounds per square foot.
720 = Inches of water.
26 = Pounds per square inch.
74 = Inches of water.
385 = Pounds per square foot.
60 = Feet of water.
26 = Pounds per square inch.
5 = Feet of water.
312 = Pounds per square foot.
15 = Inches of mercury.
17 = Feet of water.

99 = Atmospheres.

2960 = Inches of mercury.

34 = Atmospheres.

500 = Pounds per square inch.

34 = Atmospheres.

7200 = Pounds per square foot.

30 = Atmospheres.

31 = Kilogs per square centimetre.

23 = Atmospheres.

780 = Feet of water.

3 = Atmospheres.

31 = Metres of water.

29 = Pounds per square inch.

67 = Feet of water.

1 = Kilogs per square centimetre.

10 = Metres of water.

COMBINATIONS.

43 = Pounds per foot.

64 = Kilogs per metre.

127 = Pounds per yard.

63 = Kilogs per metre.

46 = Pounds per square yard.

25 = Kilogs per square metre.

49 = Pounds per cubic foot.

785 = Kilogs per cubic metre.

27 = Pounds per cubic yard.

16 = Kilogs per cubic metre.

89 = Cubic feet per minute.

42 = Litres per second.

700 = Imperial gallons per minute.

53 = Litres per second.

840 = U. S. gallons per minute.

53 = Litres per second.

38 = Weight of fresh water.

39 = Weight of sea water.

5	=	Cubic feet of water.
312	=	Weight in pounds.
1	=	Imperial gallons of water.
10	=	Weight in pounds.
3	=	U. S. gallons of water.
25	=	Weight in pounds.
50	=	Pounds per U. S. gallon.
6	=	Kilogs per litre.
10	=	Pounds per imperial gallon.
1	=	Kilogs per litre.
30	=	Pounds per U. S. gallon.
25	=	Pounds per imperial gallon.
3	=	Cubic feet of water.
85	=	Weight in kilogs.
46	=	Imperial gallons of water.
209	=	Weight in kilogs.
14	=	U. S. gallons of water.
53	=	Weight in Kilogs.
44	=	Feet per second.
30	=	Miles per hour.
88	=	Yards per minute.
3	=	Miles per hour.
41	=	Feet per second.
750	=	Metres per minute.
82	=	Feet per minute.
25	=	Metres per minute.
340	=	Footpounds.
47	=	Kilogrammetres.
72	=	British horse power.
73	=	French horse power.
3700	=	One cubic foot of water per minute under one foot of head.
7	=	British horse power.
75	=	One litre of water per second under one metre of head.
1	=	French horse power.

In no case does the departure, in these equivalents, from the exact ratio attain 1 per thousand.

EXAMPLES.

What is the pressure in pounds per square inch equivalent to a head of 34 feet of water?

C	Set 60	Under 34
D	To 26	Find 14.75 pounds—Answer.

What head of water, in feet, is equivalent to a pressure of 18 pounds per square inch?

C	Set 26	Under 18
D	To 60	Find 41.5 feet—Answer.

How many horse power will 50 cubic feet of water per minute give under a head of 400 feet?

C	Set 3700	Runner to 400	1 to R	Under 50
D	To 7			Find 37.8 H. P.—Answer.

METHODS OF WORKING OUT MECHANICAL AND OTHER FORMULÆ.

1.—Diameters and Areas of Circles. $A = .7854\ D^2$

A	To 205		A	To 11	
B	Set 161	Find Areas.	B	Set 6	Find Areas in square feet.
C		or	C		
D		Above Diameters	D		Above Diameters in inches

2.—To Calculate Selling Prices of Goods, with Percentage of Profit on Cost Price.

C	Set 100	Below cost price.
D	To 100 plus percentage of profit	Find selling price.

3.—To Calculate Selling Prices of Goods, with Percentage of Profit on Selling Price.

C	Set 100 less percentage of profit	Below cost price
D	To 100	Find selling price.

Example: If goods cost 45 cents a yard, at what price must they be sold to realize 15 per cent. profit on the selling price?

C	Set 85 (=100—15)	Below 45
D	To 100	Find 53—Answer.

4.—To find the Area of a Ring. $A=\frac{(D+d)\times(D-d)}{1.2732}$

C	Set sum of the two diameters	Find area.
D	To 1.273	Above difference of the two diameters

5.—Compound Interest.

Set the left index of C, to 100 plus the rate of interest, on D, then take the corresponding number on the scale of Equal Parts, and multiply it by the number of years. Set this product on the scale of E. P. to the index on the under side of the Rule, then on D will be found the amount of any coinciding sum on C for the given years at the given rate.

Example: Find the amount of \$150 at 5 % at the end of 10 years.

C	Set 100	E. P.=21.2×10=212	212 to I	C	Below \$150
D	To 105	Under side of Rule and	Slide.	D	Find \$244.35—Answer.

We thus obtain on D, below 1 on C, a gauge-point for 10 years at 5 %, and can obtain in like manner similar ones for any other number of years and rate of interest.

6.—Levers.

C	Set distance from fulcrum to power or weight applied	Find power or weight transmitted
D	To " " " " " transmitted	Above power or weight applied.

7.—Diameter of Pulleys or Teeth of Wheels.

In'd C	Set diameter or teeth of Driving	Diameter or teeth of Driven
D	To revolutions of Driving	Revolutions of Driven.

or,

C	Set diameter or teeth of Driving	Revolutions of Driven
D	To diameter or teeth of Driven	Revolutions of Driving.

8.—Diameter of two Wheels to work at given Velocities.

C	Set distance between their centres	Find diameter
D	To half Sum of their revolutions	Above revolutions of each.

Example: A shaft makes 21 revolutions, and is to drive another shaft which should make 35 revolutions. The distance between their centres is 48 inches. What should be the diameters of the gears?

C	Set 48	Find 36	Find 60.
D	To 28 (=21+35÷2)	Above 21	And above 35

The two wheels must therefore be 36 and 60 inches diameter.

9.—Strength of Teeth of Wheels.

$$P=\frac{\sqrt{H}}{0.6V}$$

A	To H. P. to be transmitted			
B				
C	Set gauge-point 0.6	R to 1	Velocity in ft. per second to R	Under 1
D				Pitch in inches.

10.—Diameter and Pitch of Wheels.

$$N=\frac{D\times\pi}{P}$$

C	Set 226	R to 1	Pitch to R	Under diameter of pitch circle
D	To 710			Find number of teeth.

11.—Strength of Wrought Iron Shafting.

$$D=\sqrt[3]{\frac{83\ H}{N}}$$ for crank shafts and prime movers.

$$D=\sqrt[3]{\frac{65\ H}{N}}$$ for ordinary shafting.

A	To 83 or 65		
B	Set revolutions per min.	R to Ind. H. P.	Number coinciding with R—diameter.
C			Under 1
D			Same coinciding number—diameter.

Note.—In this, as in other cases, the coefficients (83 and 65) may be altered to suit individual opinions, without in any way altering the methods of solution.

12.—To find the Change Wheel in a Screw-Cutting Lathe.

$$N=T\frac{S\times W}{M\times P}$$

$$W=N\frac{M\times P}{T\times S}$$

Where

N = Number of threads per inch to be cut.
T = " " " " on traverse screw.
M = " teeth in wheel on mandril.
W = " " stud wheel (gearing in M).
P = " " stud pinion (gearing in S).
S = " " wheel on traverse screw.

C	Set T	R to P	S to R	Under M
D	To N			Find number of teeth in W or stud wheel.

13.—Rules for Good Leather Belting. $$W=\frac{600 \text{ or } 375 \text{ H. P.}}{V \text{ ft. per min.}}$$

C	Set 600	Find width in inches	for Single Belts.
D	To velocity in feet per min.	Above actual horse power	
C	Set 375	Find width in inches	for Double Belts.
D	To velocity in feet per min.	Above actual horse power	

14.—Best Manilla Rope Driving.

A	To velocity in feet per min.	Find Actual Horse Power.
B	Set 307	
C		Above diameter in inches
D		

A	To 4	Find Strength in Tons.
B		
C	Set 1	Above diameter in inches
D		

A	To 107	Find Working Tension in Pounds.
B		
C	Set 1	Above diameter in inches
D		

A	To 0.28	Find Weight per Foot in Pounds.
B		
C	Set 1	Above diameter in inches
D		

15.—Weight of Iron Bars in Pounds per Foot length.

A	To 1	Weight of Square Bars.
B	Set 3	
C		Above width of side in inches.
D		

A	To 55	Weight of Round Bars.
B	Set 21	
C		Above diameter in inches
D		

C	Set 0.3	Below thickness in inches
D	Breadth in inches	Weight of Flat Bars.

16.—Weight of Iron Plates in Pounds per Square Foot.

C	Set 32	Below thickness in thirty-seconds of an inch.
D	To 40	Find weight in pounds per square foot.

17.—Weights of other Metals.

C	Set 1	Below G. P. for other metals
D	To weight in iron	Find weight in other metals.

Gauge-points of other metals, and weight per cubic foot.

	W. I.	C. I.	Cast Steel.	Steel Plates.	Copper.	Brass.	Lead.	Cast Zinc.
G. P.	1	.93	1.02	1.04	1.15	1.09	1.47	.92
Weight	480	450	490	500	550	525	710	440 pounds.

Example: What is the weight of a bar of copper, 1 foot long, 3 inches broad and 2 inches thick?

C	Set 0.3	R to 2 inches thick	1 to R	Below G. P. 1.15
D	To 3 inches broad			Find 23 pounds—Answer.

18.—Weight of Cast Iron Pipes.

C	Set .4075	Below Difference of inside and outside diameters in inches
D	To Sum of inside and outside diameters in inches	Find weight in pounds per lineal foot.

G. P. for other metals	Brass.	Copper.	Lead.	W. Iron.
	.355	.333	.259	.38

19.—Safe Load on Chains.

A		Safe load in tons.
B	Set 36	Above 1
C		
D	To diameter in sixteenths of an inch	

20.—Gravity.

C	Set 1	Below 32.2
D	To seconds	Velocity in feet per second.

A	Space fallen through in feet	
B		
C	Set 1	Under 8
D		Velocity in feet per second.

A		Space fallen through in feet.
B		Above 16.1
C	Set 1	
D	To seconds	

21.—Oscillations of Pendulums.

A		
B	Set length pendulum in inches	
C		Below 1
D	To 375	Number oscillations per minute.

22.—Comparison of Thermometers.

C	Set 5	Degrees Centigrade
D	To 9	Degrees + 32 = Fahrenheit.

C	Set 4	Degrees Reaumur
D	To 9	Degrees+32=Fahrenheit.

C	Set 4	Degrees Reaumur
	To 5	Degrees Centigrade.

23.—Force of Wind.

A		
B	Set 10	Find pressure in pounds per square foot.
C		
D	To 66	Velocity in Feet *per second.*

A		
B	Set 10	Find pressure in pounds per square foot.
C		
D	To 45	Velocity in Miles *per hour.*

24.—Discharge from Pumps.

A		Gallons delivered per stroke.
B	Set 29.4	Stroke in feet
C		
D	To diameter in inches	

25.—Diameter of Single-acting Pumps.

A	To 29.4			
B	Set length stroke in ft.	R to gallons to be delivered per min.	No. strokes per min. to R	
C				Below 1
D				Diam. pump in inches.

26.—Horse Power required for Pumps.

C	Set G. P.	Height in feet to which the water is to be raised
D	To cubic feet or gallons to be raised per minute	Horse power required.

Gauge Points with different Percentages of Allowance.

Per cent.	None	10	20	30	40	50	60	70	80
For Gallons, Imp.	3300	3000	2750	2540	2360	2200	2060	1940	1835
" C. Feet	528	480	440	406	377	352	330	311	294
" U. S. Gallons	3960	3600	3300	3050	2830	2640	2470	2330	2200

27.—Theoretic Velocity of Water for any Head.

A	Head in feet	
B		
C	Set 1	Under 8
D		Velocity in feet per second.

28.—Theoretical Discharge from an Orifice 1 inch Square.

A			If the hole is round and 1 inch diameter, the G. P. is 2.62.
B	Set 1	Under head in feet	
C			
D	To G. P. 3.34	Discharge in cubic feet per minute.	

29.—Real Discharge from Orifice in a Tank, 1 inch Square.

A			If the hole is round and 1 inch diameter, the G. P. is 1.65.
B	Set 1	Under head in feet	
C			
D	To 2.1 G. P.	Discharge in cubic feet per minute with coefficient .63.	

Gauge Points for other coefficients.

Coefficient	.60	.66	.69	.72	.75	.78	.81	.84	.87	.90	.93	.96
G. P. Square,	2.	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.	3.1	3.2
" Round,	1.57	1.73	1.80	1.88	1.96	2.04	2.12	2.20	2.28	2.36	2.44	2.52

30.—Discharge from Pipes when real Velocity is known.

	A		Discharge in cubic feet per minute.
Inverted	C		Above 1.75
	B	Velocity in feet per second	
	D	Diameter in inches	

31.—Delivery of Water from Pipes. $W = 4.71 \sqrt{\frac{D^5 H}{L}}$

Eytelwein's Rule.

C	Set 1	E P × 5 = x	x to I	
D	To diameter in inches	Under side of Rule.		*(Continue to next line.)*

A				To Z	
B				Set 1	
C	R to 1	Length in feet to R	Under head in feet		Under 4.71
D			Find Z		Cubic ft. per min.

This is worked out similarly to Formula 5, which is explained in full.

32.—Gauging Water with a Weir.

	A		
Inverted	C		
	B	Depth in inches	Under 4.3
	D	Depth in inches	Discharge in cubic feet per minute from each foot width of sill.

33.—Discharge of a Turbine. $\frac{\sqrt{H \times V}}{0.3} = D$

	A		
Inverted	C		Under 0.3
	B	Head in feet	
	D	Square inches water vented	Cubic feet discharged per minute.

34.—Revolutions of a Turbine.

A	To head in feet			
B				
C	Set diameter in inches	R to 1840	1 to R	Under rate of peripheral velocity
D				Find revolutions per minute.

35.—Horse Power of a Turbine.

C	Set 530	R to discharge per c. ft. per min.			1 to R	Percentage useful effect.
D	Head in ft.					Horse power.

or,

A	Under head in ft.					
B						
C	Set 1	R to head in ft.	158 to R	R to vent in sq. in.	1 to R	Under useful effect
D						Horse power.

36.—Horse Power of a Steam Engine.

C	Set 21,000	R to diam.	1 to R	R to stroke in ft.	1 to R	R to rev. per min.	1 to R	Mean pressure per sq. inch.
D	To diam. in inches							Horse power.

or,

A						Horse power.
B	Set 21,000	R to stroke in ft.	1 to R	R to revolutions	1 to R	Mean pressure.
C						
D	To diam. in inches					

37.—Dynamometer; to Estimate the H. P. indicated by.

C	Set 5252	R to length of lever in feet from centre of shaft	1 to R	Under rev. of shaft per min.
D	Weight applied at end of lever in pounds, including weight of scale			Actual horse power.

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